

4.2 Crop Residue Management

Crop residue management (CRM), which calls for fewer and/or less intensive tillage operations and preserves more previous crop residue, is designed to protect soil and water resources and to provide additional environmental benefits. CRM is generally cost-effective in meeting conservation requirements and can lead to higher farm economic returns by reducing fuel, machinery, and labor costs while maintaining or increasing crop yields. Conservation tillage, the major form of CRM, was used on almost 104 million acres in 1996, over 35 percent of U.S. planted cropland area.

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Crop residue management (CRM) systems include reduced tillage or conservation tillage practices such as no-till, ridge-till, and mulch-till as well as the use of cover crops and other conservation practices that provide sufficient residue cover to help protect the soil surface from the erosive effects of wind and water (see box, "Crop Residue Management and Tillage Definitions," p. 156).

Why Manage Crop Residue?

Historically, crop residues were removed from farm fields for livestock bedding, feed, and/or other off-field purposes. Whatever residues remained on the fields after harvest were burned off primarily to control pests, plowed under, or tilled into the soil. Culturally, some farmers take pride in having their fields "clean" of residue and intensively tilled to obtain a smooth surface in preparation for planting. More recently, farmers have adopted CRM practices—with government encouragement—because of new knowledge about the benefits of leaving greater residue and the availability of appropriate

technology. CRM can benefit society through an improved environment, and farmers through enhanced farm economic returns. However, adoption of CRM may not lead to clear environmental benefits in all regions and, similarly, may not be economically profitable on all farms. Some questions remain. Public and private interests are continuing cooperative efforts to address the barriers to realizing greater benefits from CRM practices. For example, recent advances in planting equipment permit seeding new crops through heavier surface residue into untilled soil and even directly into killed sod. Long-term effects of CRM can include:

Reduced Erosion. Tillage systems that leave substantial amounts of crop residue evenly distributed over the soil surface reduce wind erosion and the kinetic energy impact of rainfall, increase water infiltration and moisture retention, and reduce surface sediment and water runoff (Edwards, 1995). Several field studies (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall and others, 1984; Sander and others, 1989) conducted on small watersheds under

Crop Residue Management and Tillage Definitions

Little or no management of residue	Crop Residue Management (CRM)				
	Conventional tillage	Reduced tillage	Conservation tillage		
			Mulch-till	Ridge-till	No-Till
	Moldboard plow or intensive tillage used	No use of moldboard plow and intensity of tillage reduced	Further decrease in tillage (see below)	Only ridges are tilled (see below)	No tillage performed (see below)
	< 15% residue cover remaining	15-30% residue cover remaining	-----30% or greater residue cover remaining-----		

Crop Residue Management (CRM) is a year-round conservation system that usually involves a reduction in the number of passes over the field with tillage implements and/or in the intensity of tillage operations, including the elimination of plowing (inversion of the surface layer of soil). CRM begins with the selection of crops that produce sufficient quantities of residue to reduce wind and water erosion and may include the use of cover crops after low residue-producing crops. CRM includes all field operations that affect residue amounts, orientation, and distribution throughout the period requiring protection. Site specific residue cover amounts needed are usually expressed in percentage but may also be in pounds. Tillage systems included under CRM are conservation tillage (no-till, ridge-till, and mulch-till) and reduced tillage.

Conservation Tillage—Any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. Two key factors influencing crop residue are 1) the type of crop, which establishes the initial residue amount and its fragility, and 2) the type of tillage operations prior to and including planting.

Conservation Tillage Systems include:

No-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

Mulch-till—The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with herbicides and/or cultivation.

Reduced Tillage (15-30% residue)—Tillage types that leave 15-30 percent residue cover after planting, or 500-1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Weed control is accomplished with herbicides and/or cultivation.

Conventional Tillage (less than 15% residue)—Tillage types that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Generally includes plowing or other intensive tillage. Weed control is accomplished with herbicides and/or cultivation.

Conventional Tillage Systems (as defined in the Cropping Practices Survey):

Conventional tillage with moldboard plow—Any tillage system that includes the use of a moldboard plow.

Conventional tillage without moldboard plow—Any tillage system that has less than 30 percent remaining residue cover and does not use a moldboard plow.

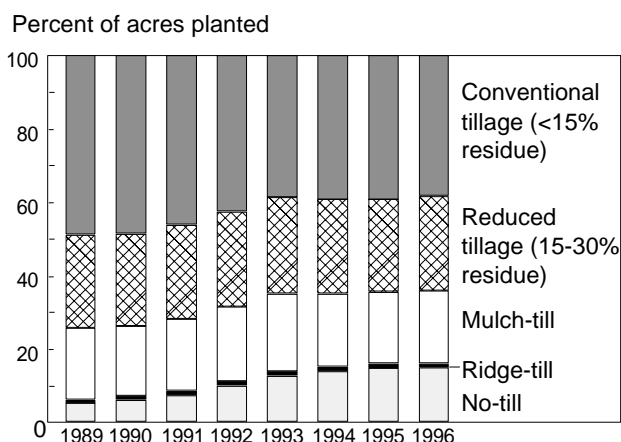
Source: USDA, ERS, based on Bull, 1993, and Conservation Tillage Information Center, 1996.

natural rainfall on highly erodible land (14 percent slope) have compared erosion rates among tillage systems. Compared with the moldboard plow, no-till reduces soil erosion by as much as 90 percent and mulch-till and ridge-till by up to 70 percent.

Cleaner Surface Runoff. Surface residues help intercept nutrients and chemicals and hold them in place until they are used by the crop or degrade into harmless components (Dick and Daniel, 1987; Helling, 1987; Wagenet, 1987). In addition, the filtering action of increased organic matter in the top layer of soil results in cleaner runoff (by reducing contaminants such as sediment and adsorbed or dissolved chemicals), and thus benefits water quality in lakes and streams (Onstad and Voorhees, 1987; Conservation Technology Information Center or CTIC, 1996). Studies under field conditions indicate that while the quantity of water runoff from no-till fields was variable depending on the frequency and intensity of rainfall, clean-tilled soil surfaces produce substantially more runoff (Edwards, 1995). Runoff from no-till and mulch-till fields averaged about 30 and 40 percent of the amounts from moldboard-plowed fields (Baker and Johnson, 1979; Glenn and Angle, 1987; Hall and others, 1984; Sander and others, 1989). Average herbicide runoff losses from treated fields with no-till and mulch-till systems for all products and all years were about 30 percent of the runoff levels from moldboard-plowed fields (Fawcett and others, 1994). Under normal production conditions, the presence of increased crop residue reduces the volume of contaminants associated with runoff to surface waters by constraining sediment losses and enhancing infiltration (Edwards, 1995; Fawcett, 1987).

Higher Soil Moisture and Water Infiltration. Crop residues on the soil surface slow water runoff by acting as tiny dams, reduce surface crust formation, and enhance infiltration (Edwards, 1995). The channels (macropores) created by earthworms and old plant roots, when left intact with no-till, improve infiltration to help reduce or eliminate field runoff. This raises the prospect of increased water infiltration carrying agricultural chemicals into the groundwater in specific situations (more discussion later of groundwater effects). Combined with reduced water evaporation from the top few inches of soil and with improved soil characteristics, the higher level of soil moisture can contribute to higher crop yields in many cropping and climatic situations (CTIC, 1996). However, in some areas, soil moisture levels can also be too high for optimal crop growth or leave soils too cool and wet at planting time, thereby reducing yields.

Figure 4.2.1--National use of crop residue management, 1989-96



Source: USDA, ERS, based on Conservation Technology Information Center data.

Possible Higher Economic Returns. CRM may result in higher economic returns from increased or stable crop yields and lower input costs. CRM systems usually involve fewer trips over a field, resulting in reduced fuel and labor requirements and lower machinery operating costs. Whether CRM in fact reduces total costs of production for farmers depends on the magnitude of the cost savings from reduced tillage operations relative to the other possible costs affected by CRM practices. For example, there may be increased costs associated with the need for specialized equipment to handle high residue on the soil surface, and increased management, labor, and materials to effectively control pest infestations. Moreover, whether CRM results in higher net returns from farming depends on the effects of CRM practices on yields as well as costs. Farmers continually face tradeoffs between advantages and limitations in choosing the tillage system most appropriate for their conditions.

Improved Long-Term Soil Productivity. Less intensive tillage reduces the breakdown of crop residues and the loss of soil organic matter. The less a soil is tilled, the more carbon is sequestered in the soil to build organic matter and maintain long-term productivity. No-till improves soil structure (tilth) by increasing soil particle aggregation (small soil clumps), which facilitates water movement through the soil and enables plants to expend less energy to establish roots. No-till can also help to minimize soil compaction through fewer trips over the field and reduced weight and horsepower requirements (CTIC, 1996).

Table 4.2.1—National use of crop residue management practices, 1989-96¹

Item	1989	1990	1991	1992	1993	1994	1995	1996
<i>Million acres</i>								
Total area planted ²	279.6	280.9	281.2	282.9	278.1	283.9	278.7	290.2
Area planted with:								
No-till	14.1	16.9	20.6	28.1	34.8	39.0	40.9	42.9
Ridge-till	2.7	3.0	3.2	3.4	3.5	3.6	3.4	3.4
Mulch-till	54.9	53.3	55.3	57.3	58.9	56.8	54.6	57.5
Total conservation tillage	71.7	73.2	79.1	88.7	97.1	99.3	98.9	103.8
Other tillage types:								
Reduced tillage (15-30% residue)	70.6	71.0	72.3	73.4	73.2	73.1	70.1	74.8
Conv. tillage (< 15% residue)	137.3	136.7	129.8	120.8	107.9	111.4	109.7	111.6
Total other tillage types	207.9	207.7	202.1	194.2	181.0	184.6	179.7	186.4
<i>Percent</i>								
Percentage of area with:								
No-till	5.1	6.0	7.3	9.9	12.5	13.7	14.7	14.8
Ridge-till	1.0	1.1	1.1	1.2	1.2	1.3	1.2	1.2
Mulch-till	19.6	19.0	19.7	20.2	21.2	20.0	19.6	19.8
Total conservation tillage	25.6	26.1	28.1	31.4	34.9	35.0	35.5	35.8
Other tillage types:								
Reduced tillage (15-30% residue)	25.3	25.3	25.7	25.9	26.3	25.8	25.2	25.8
Conv. tillage (< 15% residue)	49.1	48.7	46.1	42.7	38.8	39.3	39.3	38.4
Total other tillage types	74.4	73.9	71.9	68.6	65.1	65.0	64.5	64.2

¹ For tillage system definitions, see box "Crop Residue Management and Tillage Definitions," p. 156.

² Total area planted does not include newly established permanent pastures, fallow, annual conservation use, and Conservation Reserve Program (CRP) acres. However, it does include newly seeded alfalfa and other rotational forage crops in the year they are planted.

Source: USDA, ERS, based on Conservation Technology Information Center (CTIC) data from Crop Residue Management Surveys.

Reduced Release of Carbon Gases and Air Pollution.

Intensive tillage contributes to the conversion of soil carbon to carbon dioxide, which in the atmosphere can combine with other gases to affect global warming. Increased crop residue and reduced tillage enhance the level of naturally occurring carbon in the soil and contribute to lower carbon dioxide emissions. In addition, CRM requires fewer trips across the field and less horsepower, which reduces fossil fuel emissions. Crop residues reduce wind erosion and the generation of dust-caused air pollution (CTIC, 1996).

National and Regional CRM Use

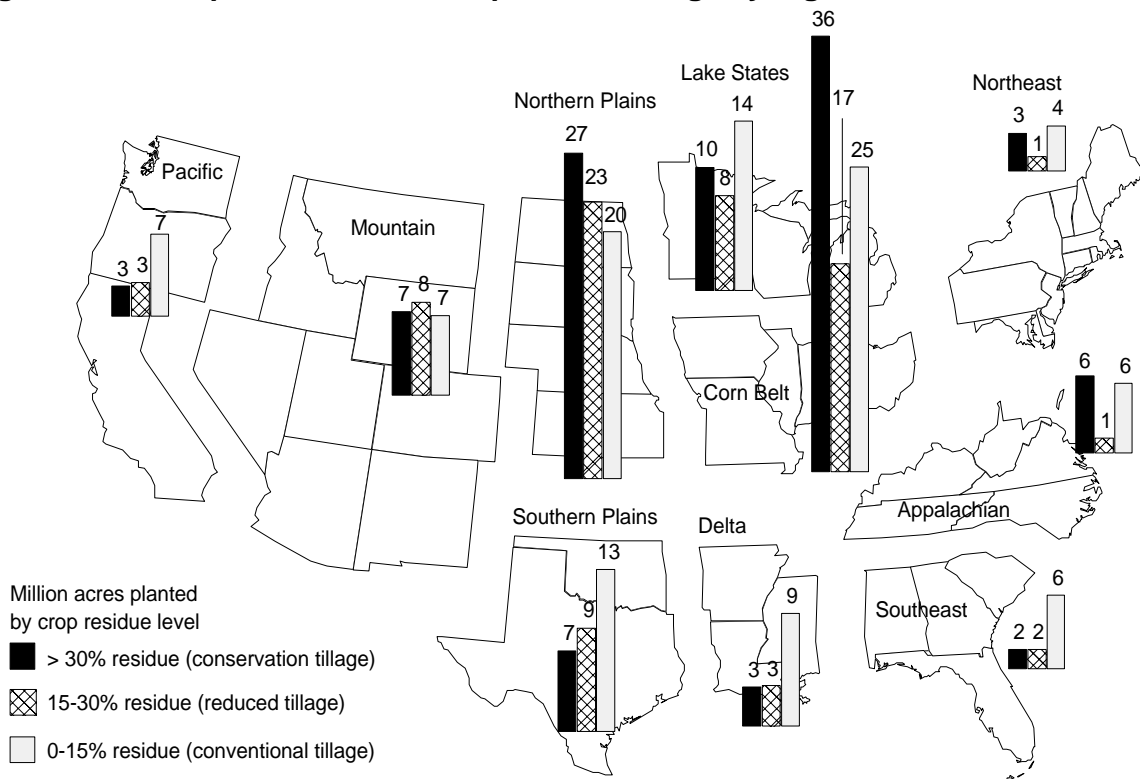
In 1996, U.S. farmers practiced conservation tillage on almost 104 million acres, up from 72 million acres in 1989 (table 4.2.1). Conservation tillage now accounts for more than 35 percent of U.S. planted crop acreage (fig. 4.2.1). Most of the growth in conservation tillage since 1989 has come from expanded adoption of no-till, which can leave as much as 70 percent or more of the soil surface covered with crop residues. Use of no-till practices increased as farmers implemented conservation compliance plans from 1990 to 1995 as required

under the Food Security Act and subsequent farm legislation.

The Corn Belt and Northern Plains, with 51 percent of the Nation's planted cropland, accounted for three-fifths of total conservation tillage acres in 1996 (fig. 4.2.2). These regions, plus the Lake States, Mountain region, and Southern Plains, have substantial acreage with 15-30 percent residue cover which, with improved crop residue management, has the potential to qualify as conservation tillage (which requires 30 percent or more surface residue cover).

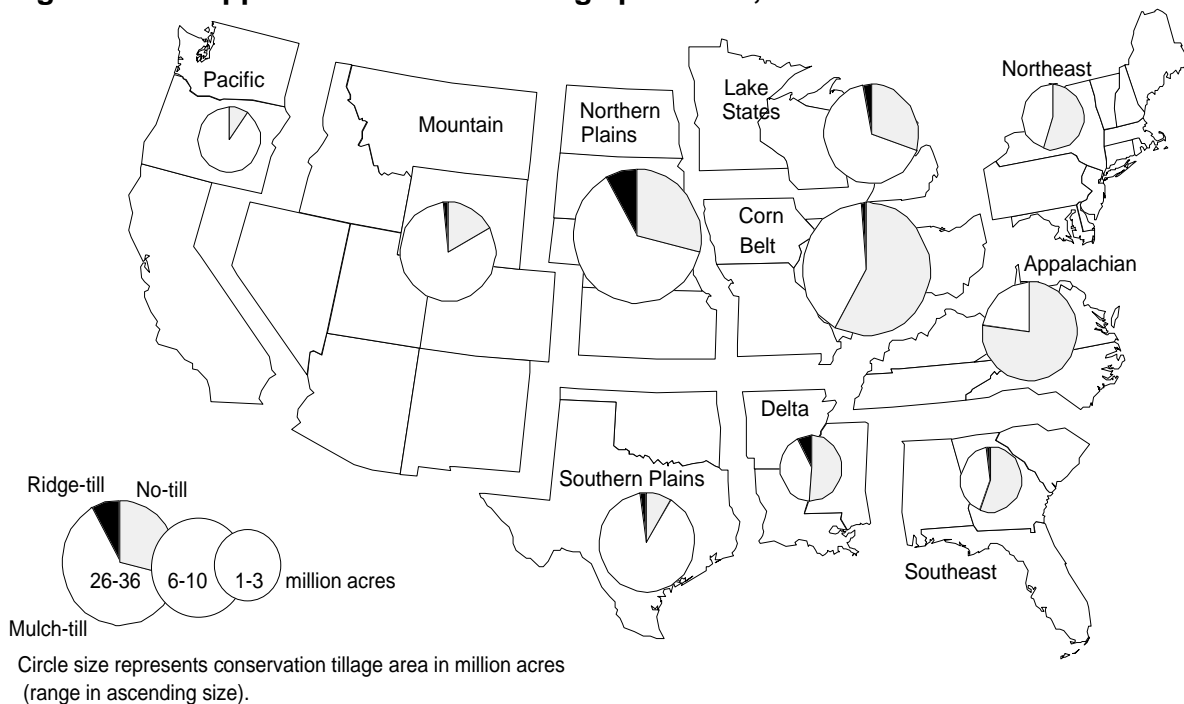
U.S. crop area planted with no-till tripled to almost 43 million acres between 1989 and 1996, while the area planted with clean tillage systems (less than 15 percent residue cover) declined by about one-fifth. Since 1989, no-till's share of conservation tillage acreage has increased while the share with mulch-till and ridge-till has remained fairly stable (fig. 4.2.1). No-till's share of conservation tilled area is greater in the six eastern regions than elsewhere (fig. 4.2.3). The aftereffects of the 1993 Midwest floods resulted in a slight decline during 1994 in acres planted (percent) with conservation tillage, mostly in mulch tillage, in the Corn Belt and Lake States (fig. 4.2.4).

Figure 4.2.2--Crop residue levels on planted acreage by region, 1996



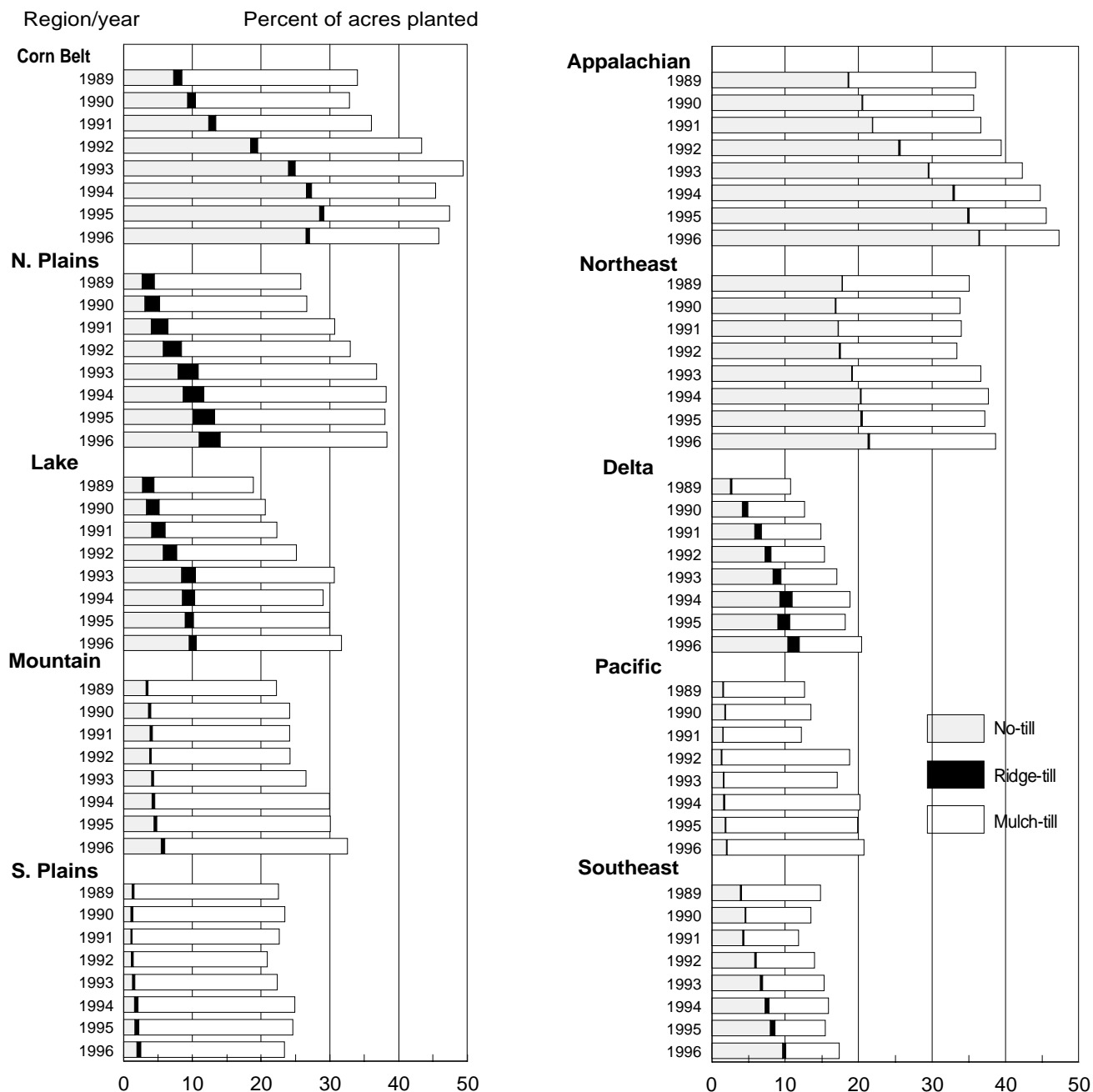
Source: USDA, ERS, based on Conservation Technology Information Center data.

Figure 4.2.3--Applied conservation tillage practices, 1996



Source: USDA, ERS, based on Conservation Technology Information Center data.

Figure 4.2.4--Conservation tillage use by region, 1989-96



Source: USDA, ERS, based on Conservation Technology Information Center data.

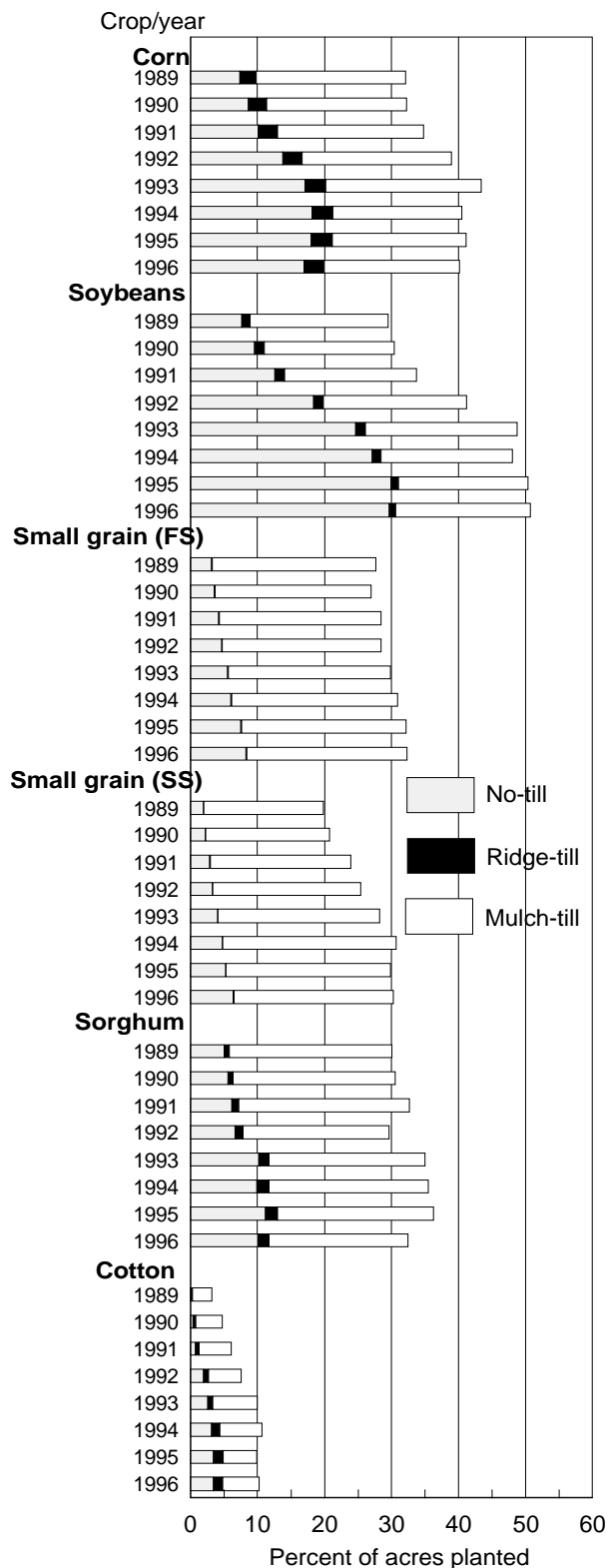
Over 1989-96, the share of acres planted with no-till showed an increase for most years in nearly all regions (fig. 4.2.4).

CRM Use on Major Crops

Conservation tillage was used mainly on corn, soybeans, and small grains in 1996. Over 45 percent of the total acreage planted to corn and soybeans was conservation-tilled. Expanded use of no-till has been

greater for row crops (that is, corn and soybeans) than for small grains or sorghum (fig. 4.2.5). Fields planted to row crops tend to be more susceptible to erosion because these crops provide less vegetative cover, especially earlier in the growing season. On double-cropped fields, conservation tillage was used on more than two-thirds of soybean acreage, more than half of corn acreage, and about half of sorghum acreage. The use of no-till with double-cropping

Figure 4.2.5--Conservation tillage use by major crop, 1989-96



FS = Fall seeded SS = Spring seeded
Source: USDA, ERS, based on Conservation Technology Information Center data.

facilitates getting the second crop planted quickly and limits potential moisture losses from the germination zone in the seedbed, allowing greater flexibility in cropping sequence or rotation (Sandretto and Bull, 1996).

The 1988-95 Cropping Practices Surveys (CPS) provide detailed data on residue levels and tillage systems for individual field crops in major producing States (for more discussion, see "Cropping Practices Survey" in the appendix). The advantages of the CPS for analysis of CRM is that it allows the linking of CRM practices to other relevant details about the farm production system, such as the type of tillage equipment used and the number of trips made over a field. These annual surveys indicate a decline in the use of the moldboard plow and other conventional tillage systems and an increase in the use of all types of conservation tillage for most of the major field crops. Less than 10 percent of the surveyed area in major producing States used a moldboard plow in 1995, down from 20 percent in 1988.

Corn. Tillage systems used for corn production in the 10 major producing States indicate a trend toward the use of conservation tillage systems (table 4.2.2). No-till systems were used on 17 percent of the acreage in 1995, up from only 5 percent in 1989, and exceeded 20 percent in several Corn Belt States. Ridge-till systems increased to 3 percent of the total acreage, but this expansion was mainly confined to Nebraska and Minnesota. A moldboard plow was used on 8 percent of 1995 corn acres, down from 20 percent in 1988.

Soybeans. Soybean production also indicated a trend toward greater use of conservation tillage systems. The 14 major soybean producing States were divided into northern and southern areas. The northern area showed a steady increase in no-till system use from 3 percent of the acreage in 1988 to 30 percent in 1995. At the same time, mulch-till increased from 14 to 24 percent and use of the moldboard plow dropped from 28 to 8 percent. The small share of soybean acreage with ridge-till was located mainly in Nebraska and Minnesota, where some soybeans are grown in rotation with ridge-till corn. The southern area increased no-till system use from 7 percent of the acreage in 1988 to 25 percent in 1995.

Cotton. Nearly all cotton was produced using conventional tillage methods in the six major cotton States. However, use of the moldboard plow decreased to less than one-half of the 1988 level. Arizona, California, and parts of Texas have State

Table 4.2.2—Tillage systems used in field crop production in major producing States, 1988-95¹

Item	Unit	1988	1989	1990	1991	1992	1993	1994	1995
Corn (10 States)	<i>1,000 acres²</i>	53,200	57,900	58,800	60,350	62,850	57,350	62,500	55,850
Residue remaining after planting	<i>Percent</i>	19	19	22	24	27	29	30	29
Conventional tillage	<i>Percent of acres</i>	80	78	74	70	61	58	57	59
With moldboard plow		20	19	17	15	12	9	8	8
Without moldboard plow		60	59	57	55	49	49	49	51
Conservation tillage		21	22	27	30	39	42	43	41
Mulch-till		14	17	18	20	25	24	23	21
Ridge-till		*	*	*	*	2	3	3	3
No-till		7	5	9	10	12	15	17	17
Northern soybeans (7 States)	<i>1,000 acres²</i>	36,550	37,750	36,400	38,850	38,150	42,500 ³	43,750 ⁴	41,700
Residue remaining after planting	<i>Percent</i>	17	19	19	25	28	35	36	38
Conventional tillage	<i>Percent of acres</i>	83	77	74	66	59	52	47	45
With moldboard plow		28	26	23	18	12	8	9	8
Without moldboard plow		55	51	51	48	47	44	38	37
Conservation tillage		17	22	27	35	41	48	53	54
Mulch-till		14	18	21	25	26	25	26	24
Ridge-till		*	*	*	*	1	1	1	1
No-till		3	4	6	10	14	22	26	30
Southern soybeans (7 States)	<i>1,000 acres²</i>	12,200	13,380	11,850	10,800	10,480	NA ⁴	NA ⁴	10,140
Residue remaining after planting	<i>Percent</i>	14	15	19	17	18	NA	NA	27
Conventional tillage	<i>Percent of acres</i>	88	87	81	83	79	NA	NA	68
With moldboard plow		3	4	4	3	3	NA	NA	1
Without moldboard plow		85	82	78	80	76	NA	NA	67
Conservation tillage		12	15	19	17	24	NA	NA	32
Mulch-till		5	5	7	6	8	NA	NA	7
Ridge-till		*	*	*	*	id	NA	NA	nr
No-till		7	10	12	11	14	NA	NA	25
Upland cotton (6 States)	<i>1,000 acres²</i>	9,700	8,444	9,730	10,860	10,200	10,360	10,023	11,650
Residue remaining after planting	<i>Percent</i>	2	2	3	3	3	2	3	3
Conventional tillage	<i>Percent of acres</i>	100	99	98	97	100	99	99	98
With moldboard plow		28	15	14	21	12	16	10	13
Without moldboard plow		72	84	84	76	88	83	89	85
Conservation tillage		id	id	2	2	id	1	1	2
Mulch-till		id	id	1	1	id	**	**	**
No-till		id	id	1	1	id	1	1	1
Winter wheat (12-15 States)⁵	<i>1,000 acres²</i>	32,830	34,710	40,200	34,180	36,990	37,210	34,590	34,265
Residue remaining after planting	<i>Percent</i>	17	17	18	17	19	18	18	20
Conventional tillage	<i>Percent of acres</i>	82	84	81	84	79	80	83	78
With moldboard plow		15	16	12	12	11	6	8	11
Without moldboard plow		67	68	69	72	68	76	75	67
Conservation tillage		17	16	20	16	21	18	17	22
Mulch-till		16	15	17	13	18	14	12	15
No-till		1	1	3	3	3	4	5	7
Spring and durum wheat (4-5 States)⁶	<i>1,000 acres²</i>	12,280	19,580	18,900	16,500	19,550	18,900	19,700	18,700
Residue remaining after planting	<i>Percent</i>	18	22	22	24	23	25	25	22
Conventional tillage	<i>Percent of acres</i>	77	68	73	66	68	65	64	73
With moldboard plow		14	8	10	7	8	8	7	6
Without moldboard plow		63	60	63	59	60	57	57	67
Conservation tillage		23	32	27	34	32	35	36	29
Mulch-till		22	31	25	31	26	28	30	22
No-till		1	1	2	3	6	7	6	5
Total acres surveyed	<i>1,000 acres²</i>	156,760	171,764	175,880	171,040	178,220	166,320	170,563	172,305
Conventional tillage	<i>Percent of acres</i>	82	79	77	74	69	65	63	64
With moldboard plow		19	17	15	14	11	8	8	8
Without moldboard plow		63	62	62	60	58	57	55	56
Conservation tillage		18	21	23	26	31	35	37	36
Mulch-till		13	17	17	19	21	21	21	19
Ridge-till		*	*	*	*	1	1	1	1
No-till		5	4	6	7	9	13	15	16

id = Insufficient data. * = Included in no-till for these years. ** = Less than 1 percent. NA = Not available.¹ For the States included, see "Cropping Practices Survey" in the appendix. For tillage system definitions, see box "Crop Residue Management and Tillage Definitions." ² Preliminary. Planted acres except for winter wheat (harvested). ³ May not add due to rounding. ⁴ Arkansas in 1993 and 1994 is included in Northern area. Previously, Arkansas was included with GA, KY, LA, MS, NC, and TN (all not surveyed in 1993 and 1994) to comprise Southern area. ⁵ Winter wheat includes 15 States in 1988-89 and 1991-92; 12 States in 1990; and 13 States in 1993-95. ⁶ Spring wheat includes 5 States in 1988-89 and 4 States in 1990-95. Durum wheat includes only ND. Source: USDA, ERS, Cropping Practices Survey data.

"plow-down" laws requiring that the cotton plant be disposed of to eliminate the over-winter food source for bollworms and boll weevils. Some producers have misinterpreted these laws to mean that the previous crop must be plowed under with a moldboard plow. California producers mainly use multiple passes with a heavy disk. In some areas of Texas, the moldboard plow is also used to bring up clay subsoil in order to cover the soil surface with clods to help control wind erosion. The large number of tillage trips across the field (averaging 6.1) leaves very little residue, even without use of the moldboard plow. Research is being conducted in a number of cotton producing States on the use of strip-till and no-till systems and the "stale seedbed" system, which uses cover crops or weeds to provide vegetative cover on the field from harvest to the next planting season.

Winter Wheat. Except for 1994 and 1995, a steady decline in moldboard plow use occurred in winter wheat production since 1988 (table 4.2.2). Meanwhile, no-till and conventional tillage without the plow showed a corresponding increase. The heavy rains and flooding in some States during 1993 affected planting of the 1994 crop. Siltation from flooding and the impact from heavy rains may have contributed to increased use of the moldboard plow in 1994 and 1995 (Bull and Sandretto, 1996).

Spring and Durum Wheat. Variations in the type of tillage system used in the production of spring and durum wheat may be partly due to weather-soil relationships in the areas producing these crops. Much of the wheat produced in the Great Plains and the Western States is grown after a fallow period. Implement passes made during the fallow year are included in determining residue levels, hours per acre, and trips over the field. Normal fallow procedure in these regions starts with chisel plowing and other noninversion tillage operations in the fall instead of a pass with a moldboard plow. For these regions, therefore, more trips over the field occur under conventional tillage without the moldboard plow than for tillage with the moldboard plow.

Factors Affecting CRM Adoption

The trend toward adoption of conservation tillage and a corresponding decline in clean tillage has been stimulated by the prospect of higher economic returns with conservation tillage and by public policies and programs promoting conservation tillage for its conservation benefits. The major limitations to adoption of soil-conserving tillage systems for some farmers include additional management skill requirements, expectations of lower crop yields and/or

economic returns in specific geographic areas or situations, negative attitudes or perceptions, and institutional constraints.

Prospects for Higher Economic Returns

Higher economic returns with CRM result primarily from some combination of increased or stable crop yields and an overall reduction in input costs, with both heavily dependent on characteristics of the resource base and appropriate management (Clark and others, 1994).

Yield Response. Yield response with soil-conserving tillage systems varies with location, site-specific soil characteristics, climate, cropping patterns, and level of management skills. In general, long-term field trials on well-drained to moderately well-drained soils or on sloping land show slightly higher no-till yields, particularly with crop rotations, compared with conventional tillage (Hudson and Bradley, 1995; CTIC, 1996). Experienced no-till farmers claim greater yields from increased infiltration and improved soil properties such as reduced erosion and soil compaction, increased soil organic matter and earthworm activity, and improved soil structure (tilth) in 4-7 years from when the system becomes established (CTIC, 1996). A mulch-till system may be more appropriate where soil varies greatly within a field, where pre-plant incorporated herbicides are used for weed control, or where equipment or management limitations preclude the use of no-till or ridge-till (CTIC, 1996).

The benefits from improved moisture retention in the root zone—that derive from reduced water runoff, increased infiltration, and suppressed evaporation from the soil surface—usually increase crop yields, especially under dry conditions. In some areas of the northern Great Plains, these benefits permit a change in the cropping pattern to reduce the frequency of moisture-conserving fallow periods (Clark and others, 1994).

Increased crop residue on the soil surface tends to keep soils cooler, wetter, and less aerated (Mengel and others, 1992). These characteristics under cool, wet planting conditions, especially in some Northern States, have been blamed for delayed plantings, uneven stands, and lower corn yields (Griffith and others, 1988). However, with hot, dry weather later in the growing season, the effects of increased organic matter, improved moisture retention and permeability, and reduced nutrient losses from erosion all benefit crop yields. No-till is particularly well suited for double-cropping because farmers can plant

Table 4.2.3—Pesticide use on corn by tillage system, 10 major producing States, 1994¹

Item	Conventional tillage		Mulch tillage	No tillage	Ridge tillage
	with moldboard plow	without moldboard plow			
Treated acres as a percent of total planted					
Herbicides					
Any herbicide	93.4	98.0	98.6	99.2	99.0
(Avg. lbs./treated acre)	(2.2)	(2.8)	(2.7)	(3.3)	(2.0)
Major active ingredients:					
Atrazine	52.3	66.5	66.6	84.0	78.1
Cyanazine	19.5	18.4	18.5	35.0	10.5
Acetochlor	2.2	7.6	8.3	4.4	6.2
Alachlor	18.0	17.2	16.4	18.1	21.3
Metolachlor	24.1	32.9	35.4	28.4	42.3
Nicosulfuron	18.1	12.5	14.7	10.4	7.9
Pendimethalin	5.2	2.6	2.1	1.7	*
2,4-D	8.9	11.2	11.6	25.8	15.3
Dicamba	29.0	28.7	36.0	20.6	22.4
Glyphosate	1.3	0.9	1.7	18.7	4.4
Bromoxynil	8.5	9.9	11.7	6.0	10.9
Insecticides					
Any insecticide	24.2	23.9	26.9	26.6	51.9
(Avg. lbs./treated acre)	(1.0)	(0.8)	(0.8)	(0.7)	(0.9)
Major active ingredients:					
Chlorpyrifos	10.2	7.5	7.7	6.7	6.0
Fonofos	3.9	2.3	1.9	1.2	9.6
Methyl parathion	*	1.8	1.8	2.7	20.6
Terbufos	4.7	6.1	7.6	6.2	10.2
Permethrin	*	2.7	2.3	6.7	6.8
Tefluthrin	*	3.4	4.4	3.9	5.8
Fungicides					
	nr	nr	nr	nr	nr

¹ For States included, see "Cropping Practices Survey" in the appendix.

nr = none reported. * = insufficient sample size.

Source: USDA, ERS, 1994 Cropping Practices Survey data.

the second crop quickly, minimizing moisture loss from the germination zone (Sandretto and Bull, 1996).

The crop grown in the previous year can have a great influence on the success of conservation tillage systems, especially no-till. The kind, amount, and distribution of previous crop residue can influence soil temperature, seed germination, and early growth. Lower seed germination and lack of early growth sometimes result from an allelopathic (negative) effect due to placing seed under or near decaying residue from the same crop or a closely related species (Griffith and others, 1992; CTIC, 1996). No-till, mulch-till, and even conventional tillage systems are more likely to be successful with crop rotation than with monoculture. Ridge-till is best suited to row crops, and therefore is often used with monoculture. However, monoculture often results in

lower yields and generally requires greater fertilizer and pesticide use compared with crop rotations, regardless of tillage system (Bull and Sandretto, 1995).

Crop yields can be significantly affected by pest populations, which frequently change under different tillage systems. Maintaining or increasing yields when changing tillage systems requires skillful use of the various means of pest control, including pesticide application, cultivation, cover crops, crop rotation, scouting, and other integrated pest management practices (see box, "Weed Control and Tillage," p. 168, for more detail).

Changes in Pesticide Use. Pesticide use on major crops differs among tillage systems, but it is difficult to distinguish the effects related to tillage systems

Table 4.2.4—Pesticide use on soybeans by tillage system, 8 major producing States, 1994¹

Item	Conventional tillage		Mulch tillage	No tillage	Ridge tillage
	with moldboard plow	without moldboard plow			
Treated acres as a percent of total planted					
Herbicides					
Any herbicide	97.9	98.1	99.4	98.0	94.1
(Avg. lbs./treated acre)	(1.0)	(1.1)	(1.1)	(1.3)	(0.9)
Major active ingredients:					
Alachlor	6.9	7.0	6.1	6.8	31.4
Metolachlor	8.2	8.1	6.8	9.3	10.1
2,4-D	0.5	1.2	3.9	35.4	25.3
Acifluorfen	4.4	12.1	8.7	8.0	nr
Fenoxaprop-ethyl	5.5	4.8	3.3	6.1	5.1
Fluazifop-P-butyl	7.7	7.4	6.9	9.9	5.1
Quizalofop-ethyl	5.2	5.6	6.2	8.6	nr
Chlorimuron-ethyl	13.6	14.4	13.0	20.1	5.1
Thifensulfuron	16.0	11.1	15.2	15.9	10.1
Imazaquin	9.0	22.0	14.2	16.7	nr
Imazethapyr	47.9	36.2	49.9	41.6	54.6
Pendimethalin	14.0	24.9	26.1	26.6	nr
Trifluralin	31.5	31.5	29.1	1.5	nr
Metribuzin	11.0	11.1	6.1	13.2	10.1
Glyphosate	1.2	1.5	4.6	54.5	40.5
Bentazon	16.0	14.0	15.4	12.6	nr
Lactofen	6.5	2.9	4.7	5.0	12.1
Sethoxydim	2.3	5.2	7.6	9.3	8.2
Insecticides			less than 1 percent overall		
Fungicides			less than 1 percent overall		

¹ For States included, see "Cropping Practices Survey" in the appendix.

nr = none reported. * = insufficient sample size.

Source: USDA, ERS, 1994 Cropping Practices Survey data.

from differences in pest populations between areas and from one year to the next, and from use of other pest control practices. Factors other than tillage that affect pest populations may have greater impact on pesticide use than type of tillage (Bull and others, 1993). The 1994 CPS data for major field crops also illustrate that differences among tillage systems tend to be more in the combinations of active ingredients applied than in the proportion of acres treated or the amount applied per treated acre.

In 1994, nearly all **corn** acres under all tillage systems were treated with herbicides (table 4.2.3). The overall application rate (pounds per acre treated) was highest for no-till and lowest for ridge-till. Differences between tillage systems were shown to be greater among the active ingredients applied than in the overall average amount applied per treated acre. Of the 11 most commonly used herbicides on corn, 2 were applied most frequently with conventional-till, 3

with mulch-till, 4 with no-till, and 2 with ridge-till. A comparison between no-tilled and conventionally tilled corn acreage shows that 6 of the 11 most commonly used herbicides were more frequently used with conventional-till and 5 were more frequently used with no-till.

The share of corn acreage treated with insecticides was slightly over one-half of ridge-tilled acres, but only about one-fourth with other tillage systems (table 4.2.3). No-till acres received slightly less insecticide per treated acre than did acreage with other tillage systems. No fungicide use was reported on surveyed corn acreage.

Most **soybean** acres under all tillage systems were treated with herbicides, but few or none were treated with insecticides or fungicides. A greater variety of herbicides were used on soybeans than on corn or wheat (table 4.2.4). Differences in the specific

herbicide active ingredients applied existed between tillage systems, but the overall average amounts applied per treated acre were similar, although slightly higher for no-till. Of the 18 most commonly applied herbicides on soybeans, 5 were applied most frequently with conventional-till, 9 with no-till, and 4 with ridge-till.

A much smaller share of **winter wheat** acreage than corn or soybeans was treated with herbicides, ranging from 39 percent of no-till acreage to 51 percent of conventionally tilled acreage (table 4.2.5).

Survey results for recent years indicate lower rates of insecticide use with no-till than with other tillage systems, partly because no-till systems are often used in combination with crop rotations. Greater and more frequent insecticide use was reported for moldboard plowing and ridge-till, respectively, both of which are characterized by continuous production of a single crop. No-till corn and soybeans received slightly higher applications of herbicides than did other tillage systems, but the additional pesticide costs are usually more than offset by substantial cost savings from reduced field operations (CTIC, 1996). Employing integrated pest management practices such as scouting to limit spraying to isolated problem areas can reduce costs and the amount of pesticide used, regardless of tillage system (Sandretto and Bull, 1996).

Impacts on Production Costs. Choice of tillage system affects machinery, chemical, fuel, and labor costs. In general, decreasing the intensity of tillage or reducing the number of operations results in lower machinery, fuel, and labor costs. These cost savings may be offset somewhat by potential increases in chemical costs depending on the herbicides selected for weed control and the fertilizers required to attain optimal yields (Siemens and Doster, 1992). The cost of pesticides with alternative tillage systems is not simply related to the total quantity of all pesticides used. Alternative pesticides (active ingredients) and/or different quantities of the same or similar pesticides are often used with different tillage systems. Newer pesticides are often used at a much lower rate but are quite often more expensive. This complicates the prediction of cost relationships between tillage systems. When making comparisons among tillage systems, the cost calculation must be based on the specific quantity and price of each pesticide used (Bull and others, 1993).

The reduction in labor requirements per acre for higher residue tillage systems can be significant and can result in immediate cost savings. Less hired labor

Table 4.2.5—Pesticide use on winter wheat by tillage system, 13 major producing States, 1994¹

Item	Coventional tillage		Mulch tillage	No tillage
	with mldbd. plow	w/out mldbd. plow		
<i>Treated acres as a percent of total planted</i>				
Herbicides				
Any herbicide	49.4	50.6	43.1	38.7
(Avg. lbs./treated acre)	(0.45)	(0.35)	(0.38)	(0.43)
Major active ingredients:				
2,4-D	14.4	24.4	28.9	14.2
MCPA	7.7	4.9	3.0	8.5
Chlorsulfuron	25.5	15.1	4.5	nr
Metsulfuron-methyl	7.9	13.7	17.9	nr
Thifensulfuron	5.8	4.2	3.3	13.3
Tribenuron-methyl	6.1	4.2	4.2	14.2
Triasulfuron	5.3	5.6	3.6	*
Dicamba	5.1	10.3	8.7	*
Insecticides				
<i>less than 1 percent overall</i>				
Fungicides				
<i>less than 1 percent overall</i>				

¹ For States included, see "Cropping Practices Survey" in the appendix.
nr = none reported. * = insufficient sample size.

Source: USDA, ERS, 1994 Cropping Practices Survey data.

results in direct savings, while less operator or family labor leaves more time to generate additional income by expanding farm operations or working at off-farm jobs. However, the benefits from tillage systems that reduce labor and time requirements may be greater than perceived from just the cost savings per acre. Consideration must be given to the opportunity cost of the labor and time saved. Farmers who spend less time in the field have more time for financial management, improved marketing, or other activities to improve farm profitability (Sandretto and Bull, 1996).

Making fewer trips over the field also means that equipment lasts longer and/or can cover more acres. In either case, machinery ownership costs per acre are reduced (Monson and Wollenhaupt, 1995). In addition, the size and number of machines required decline as the intensity of tillage or the number of operations is reduced. This can result in significant savings in operation and maintenance costs. Fewer trips alone can save an estimated \$5 per acre on machinery wear and maintenance costs (CTIC, 1996). While new or retrofitted machinery may be required to adopt conservation tillage practices, machinery costs usually decline in the long run because a

smaller complement of machinery is needed for high-residue no-till systems. Conservation tillage equipment designs have improved over the last decade and these improvements enhance the opportunity for successful conversion to a CRM system. Farm equipment manufacturers are now producing a wide range of conservation tillage equipment suitable for use under a variety of field conditions (Sandretto and Bull, 1996).

Reducing the intensity or number of tillage operations also lowers fuel and maintenance costs. Fuel costs, like labor costs, can drop nearly 60 percent per acre by some estimates (Monson and Wollenhaupt, 1995; Weersink and others, 1992). If fuel prices increase, conservation tillage practices become relatively more profitable.

Several studies report that on a range of soil types, higher residue tillage systems such as no-till and ridge-till result in greater economic returns for a given crop than lower residue systems. Even in some northern areas with heavy wet soils where no-till yields have sometimes been slightly lower, net returns have often been better because per-acre costs were lower (Doster and others, 1994; Fox and others, 1991).

The net returns on the entire operation can increase even if returns for a particular crop on a farm do not. For example, a tillage system that requires substantially less labor per acre and reduces returns per acre slightly but that permits application of the labor savings to more acres could result in larger total returns (Sandretto and Bull, 1996).

Policies and Programs Affecting CRM Adoption

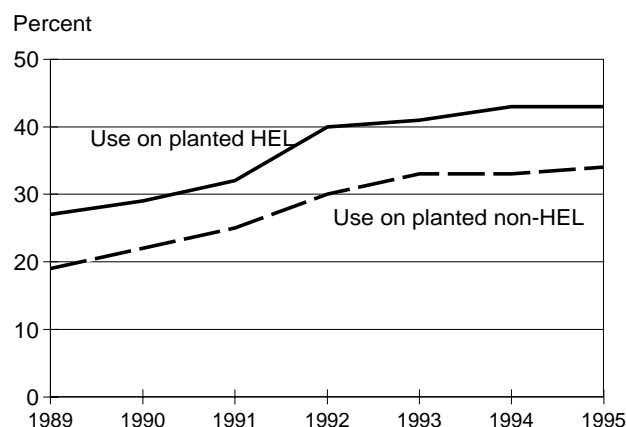
The 1985 Food Security Act gave farmers an additional incentive to adopt CRM when it instituted the Conservation Compliance program to protect highly erodible land (HEL) by controlling erosion. Under the program, farmers who produce crops on HEL and fail to implement an approved conservation plan forfeit eligibility for most USDA farm program benefits (see chapter 6.4, *Conservation Compliance*). Crop residue management (including conservation tillage) is a key component in the conservation plans for around 75 percent of the 91 million acres of cultivated HEL subject to compliance. The 1990 Food, Agriculture, Conservation, and Trade Act further strengthened the Federal role of protecting soil and water resources. Besides increasing penalties for noncompliance, the Act established other programs that offer incentives to adopt practices such as CRM to improve water quality or control erosion (see

chapter 6.1, *Conservation and Environmental Programs Overview*).

In 1991, USDA developed the Crop Residue Management Action Plan to assist producers with highly erodible cropland in implementing conservation systems that met the requirements of their approved conservation plans by the 1995 deadline. The plan increased the timely delivery of information, provided technical assistance to help land users install conservation systems, helped producers better understand the conservation provisions of farm legislation, and assisted them in maintaining their conservation plans and thus their eligibility for USDA program benefits. Crop Residue Management (CRM) alliances were established at the National, State, and local levels. The 20 State alliances, some of which remain active, included USDA agencies, agricultural supply industries, farm media, grower associations, commodity groups, conservation and environmental organizations, universities, and others interested in promoting the conservation of soil and water resources. USDA continues to provide assistance to farmers to meet conservation compliance requirements.

Adoption of conservation tillage practices, especially no-till, has been greater on HEL than on non-HEL (fig. 4.2.6). In 1995, conservation tillage was used on 43 percent of HEL acreage planted to major field crops in the primary producing States, compared with 34 percent for non-HEL. However, the rate of

Figure 4.2.6--Use of conservation tillage on HEL and non-HEL, major crops and growing States, 1989-95



See "Cropping Practices Survey" in the appendix for crops and States included.

Source: USDA, ERS, Cropping Practices Survey data.

Weed Control and Tillage

Crop yields can be significantly affected by weed populations. Traditional tools for controlling weeds have included crop rotations, crop or cover crop competition, and row crop cultivation and they play an important role in combination with modern pesticides to achieve effective pest control. These tools combined with scouting comprise the core of what has become known as integrated pest management (IPM). IPM is a systematic way of controlling pests (weeds, insects, and diseases) using a variety of techniques. The results from an effective IPM program often include higher profits due to savings from reduced pesticide applications and improved protection of the environment (CTIC, 1996).

Weed control problems vary among tillage systems because the nature of the weed population changes. An understanding of the response of weed species to tillage systems is essential in designing effective weed management programs (Martin, 1995). Actively tilling the soil before planting (and cultivating during the growing season for row crops) helps provide weed control in conjunction with herbicides. However, tillage also brings up dormant weed seeds and prepares a seedbed not only for the crop, but for weed seeds as well (Monson and Wollenhaupt, 1995). Tillage can also expand the perennial weed problem of some species by spreading their rhizomes and tubers (Kinsella, 1993). A challenge with no-till in some areas involves a gradual shift from annual weeds to several hard-to-control perennial weeds, including woody species and volunteer trees after 7-10 years (CTIC, 1996).

Mechanical cultivation for weed control is only feasible on the share of the cropland acreage planted with a row planter. The reported Cropping Practices Survey incidence of mechanical cultivation was fairly consistent across tillage systems except for higher use with ridge-till and considerably lower (one-third to one-half of the share of acres treated for other tillage systems) use with no-till. Ridge-till systems normally use mechanical cultivations during the season to rebuild and maintain the ridges in addition to controlling weeds.

Crop rotation can be an important tool for weed control because certain weeds are easier or more economical to control in one crop than another. For example, perennial grasses that are difficult to control in corn can be managed effectively in broadleaf crops such as cotton and soybeans (CTIC, 1996). Conversely, some broadleaf weeds are much easier to control in corn than in soybeans. A competitive crop that can achieve early shading of weeds can greatly improve weed control. The success of this system depends on obtaining a quick-closing crop canopy to shade emerging weeds and good stand establishment since skips allow some weeds to escape. Cover crops can accomplish this goal by reducing the amount of sunlight that reaches emerging weed seedlings (CTIC, 1996). In addition, crop rotations can often reduce the area needing treatment with pesticides and also decrease reliance on annual applications of the same pesticide; the latter pattern can increase pest resistance and reduce pesticide effectiveness.

Herbicide effectiveness depends on spraying at the right stage of growth and of plant stress, and under favorable weather conditions. Recommendations on the type and combination of herbicides and method of application for efficient weed control vary among tillage systems. The effective use of post-emergence herbicides most commonly employed in high residue situations requires careful and regular scouting and better knowledge of weed identification to facilitate appropriate herbicide selection. Herbicide application rates for ridge tillage were consistently lower than for other systems due to more prevalent banding, which uses smaller amounts of chemicals and more mechanical cultivation. Because no-till employs limited (or no) mechanical tillage, proper application of herbicides is essential for effective weed control. In addition, during the transition to higher residue systems, farmers often tend to increase slightly the amount of herbicide used as a risk aversion measure. The reported Cropping Practices Survey increase by no-till users in herbicide application (by weight) is due in part to the inclusion of an additional "burndown" herbicide treatment prior to planting as a substitute for mechanical weed control. However, successful no-till users find that herbicide costs generally decrease and become competitive with conventional tillage systems in 3-5 years (CTIC, 1996). Also, different management skills are required to control weeds with no-till or other high-residue tillage systems than with intensive tillage systems (CTIC, 1996). Crop residue management systems do not necessarily increase agricultural chemical requirements or application costs. The trend toward precision farming means that increasingly agricultural chemicals, including fertilizers and pesticides, will be carefully managed in a manner tailored to the site-specific conditions and the problems to be corrected. Improved input management is becoming necessary to ensure economic viability, maintain long-term productivity, and protect environmental quality.

increase in the use of conservation tillage on non-HEL was similar to that on HEL, suggesting that all producers are motivated by the potential of conservation tillage systems to reduce costs, improve efficiency, and/or increase soil productivity. Also, once a producer implements conservation tillage on HEL to stay in compliance, using the same equipment and techniques on his non-HEL makes good economic sense. The use of conservation tillage has leveled off in several regions since 1993 due in part to unusual weather patterns—primarily heavy rainfall—and cool planting conditions unfavorable for conservation tillage.

In passing the Federal Agriculture Improvement and Reform Act of 1996, Congress reaffirmed its preference for dealing with agricultural resource problems using voluntary approaches. The Act continued the Conservation Compliance Program and gave farmers greater flexibility in meeting requirements. The Act also established the Environmental Quality Incentives Program (EQIP) to replace previous financial and technical assistance programs and to better target assistance to areas most needing actions to improve or preserve environmental quality. While half of EQIP funding is to be directed to environmental practices relating to livestock production, the other half will be for other conservation improvements, which could include incentives (financial and technical assistance) for implementation of improved crop residue management. Directing the program toward management practices would favor crop residue management. Crop residue management, including conservation tillage, is a particularly cost-effective method of erosion control (requiring fewer resources than intensive structural measures such as terraces) that can be implemented in a timely manner to meet conservation requirements. The cost-savings from reduced fuel, labor, machinery, and time requirements, while usually maintaining or increasing crop yields, make greater adoption of CRM likely. (For more information on programs, see chapter 6.1, *Conservation and Environmental Programs Overview*.)

Barriers to CRM Adoption

Given the conservation and potential economic advantages of conservation tillage systems, and the promotion that has occurred, why aren't the systems used on more than 35 percent overall of U.S. cropland? First, adoption is the final step in a process that begins with becoming aware, moves to gaining information, then to trial, and finally to adoption. A number of farmers are in the reduced tillage transition stage between conventional intensive tillage and

conservation tillage, or who are currently trying conservation tillage on part of their land, and will likely make further change. Second, there are particular soils and climatic or cropping situations where conservation tillage systems have not yet demonstrated that they can consistently produce good economic results. In these areas, most farmers are waiting for the development of improved systems. Further limiting factors include the additional management skill requirements and economic risk involved in changing systems, attitudes and perceptions against new practices, and, in some cases, institutional constraints.

Some farmers' attitudes against adoption of new technologies, including conservation tillage, derive from a reluctance to change from methods of production that have proven to be successful in terms of their own experience. The superiority of new techniques have to be demonstrated to a sufficient extent to offset exposure to the risks inherent in making a change from traditional methods. The perceived risks are critical because unusual weather or pest problems may be accepted as a normal occurrence with traditional methods but may be blamed on the new tillage system if they occur during the transition period. Consequently, the new technique may be unfairly discredited in the area for a long time if initial attempts result in failure.

Cultural and institutional factors can also constrain adoption. Some farmers or even whole communities demonstrate strong preferences for clean tilled fields as a sign of "good" management. The banker and/or landlord may be reluctant to permit a change in the way the land is farmed especially if they perceive more potential risk to crop yields and net returns during the transition.

Farmers are aware that a series of challenges exist with higher residue levels. These may include different (but not necessarily more serious) disease, insect, or weed problems; difficulties with more residue on the surface in proper seed, fertilizer, and pesticide placement; and, under certain conditions, particularly cool wet seasons, lower corn yields (CTIC, 1996). In addition, the land must be properly prepared for no-till (previous compaction and fertility problems need to be corrected first), and the transition period (2-4 years) can be very difficult as the farmer wrestles with learning how to adapt the new tillage system to his unique situation, especially if unusual weather or pest problems arise during the transition, because long-term benefits such as improved soil quality may take 4-7 years to be realized. However,

in many situations, innovative farmers have found solutions to most of these problems or through experience have learned how to reduce their impact to tolerable levels until more acceptable solutions can be devised.

Farmers often face significant tradeoffs when choosing the most appropriate tillage system for their conditions. Higher residue systems generally allow less opportunity to correct mistakes or adjust to changed circumstances once the season is underway. Conservation tillage practices, with their higher levels of crop residue, usually require more attention to proper timing and placement of nutrients and pesticides, and in carrying out tillage operations. Nutrient management can become more complex with crop residue management because of higher residue levels and reduced options with regard to method and timing of nutrient applications. No-till in particular can complicate manure application and may also contribute to nutrient stratification within the soil profile from repeated surface applications without any mechanical incorporation. In those cases where nutrients cannot be utilized effectively by plant roots that are deeper in the soil profile, the problem can usually be avoided by correcting prevalent nutrient deficiencies prior to the switch to no-till. With higher residue levels, however, evaporation is reduced and more water is maintained near the surface, which favors the growth of feeder roots near the surface where the nutrients are concentrated (Monson and Wollenhaupt, 1995). But in some instances, increased application of specific nutrients may be necessary and specialized equipment required for proper fertilizer placement, thereby contributing to higher costs.

Effects of CRM on Groundwater Quality

Enhanced infiltration of water under crop residue management raises concerns about whether there are greater adverse effects on groundwater than with conventional clean tillage. The issue continues to be analyzed; the difficulty of tracking a pesticide once it has been applied further complicates attempts to find an answer. While conservation tillage systems can change weed and insect problems and the kinds of herbicides and insecticides used, total use of pesticides does not change greatly when farmers convert to conservation tillage (tables 4.2.3-4.2.5) (Fawcett, 1987; Fawcett and others, 1994; Hanthorn and Duffy, 1983). Analyses of pesticide quantities by tillage system generally conclude that appropriate conservation tillage systems are no more likely to degrade water quality through chemical contamination than other tillage systems, and do not increase the risk of undesirable impacts from pesticides on human

health and aquatic life (Baker, 1980; Baker, 1987; Baker and others, 1987; Baker and Laflen, 1979; Edwards and others, 1993; Fawcett and others, 1994; Melvin, 1995; Wagenet, 1987). For a specific site, the effects depend on a complex set of factors besides the infiltration rate, including properties of the chemicals applied, quantities applied, timing of application, method of application, and a variety of site specific factors (climatic, hydrologic, geologic, and topographic) (Onstad and Voorhees, 1987; Wagenet, 1987). Also, one has to consider what the cropping pattern and chemical use would be in the absence of CRM. In any situation, some of the factors may contribute to less effect and others to greater effect, with detailed analysis required to determine the net result. Some observations on these factors follow.

The potential for higher infiltration with conservation tillage creates an opportunity for groundwater degradation in some circumstances, such as for highly permeable sandy soils over shallow groundwater aquifers (Baker, 1987; CTIC, 1996; Wauchope, 1987). However, increased infiltration also normally dilutes the concentration of contaminants in the percolate to ground water (Bengtson and others, 1989; USDA, ERS, 1993).

The fate of applied chemicals is particularly dependent on the respective properties of the active ingredients, such as their adsorption, persistence, solubility, and volatility (Dick and Daniel, 1987; Fawcett, 1987; Melvin, 1995; Wauchope and others, 1992). Chemicals with high water solubility and low adsorption characteristics are highly mobile and possess the potential for loss through surface runoff or subsurface drainage (leachate) (Moldenhauer and others, 1995; USDA, ERS, 1993).

Pesticides that are strongly adsorbed to soil, sediment particles, or organic matter are protected from chemical or biological degradation and volatilization while adsorbed to these materials. Pesticides that are tightly held will not readily leach to ground water and will be found in surface-water runoff only under erosive conditions where the particles to which they are attached are washed off the fields. The soil adsorption property is a major factor affecting the pollution potential of a particular pesticide (Melvin, 1995; Wauchope and others, 1992; Weber and Warren, 1993).

The behavior of chemical compounds in the environment is also influenced by the application method. For example, whether a pesticide is applied

to foliage or the soil or is incorporated into the soil makes a big difference in how easily the application deposits can be dislodged by rain, and thus be leached into the soil or transported in surface runoff. Soil incorporation physically lowers the susceptibility of a pesticide to volatilization and thereby increases its persistence (Wauchope and others, 1992).

Early pre-plant (EPP) herbicides are applied several weeks or months prior to crop planting. Their advantages include prevention of weed establishment, elimination of the need for burndown treatments at planting, reduction in the potential for herbicide carryover from one crop season to the next, and the spreading out of labor related to planting. However, there are disadvantages to EPP herbicides particularly on sloping or highly erodible cropland. Occasional heavy rains on unprotected sloping fields can cause soil erosion and high rates of surface runoff even with no-till systems, and chemicals (attached to soil particles or dissolved in runoff water) could enter waterways. Use of EPP herbicides should be avoided on sandy soils or other soil types with high leaching potential (CTIC, 1996). Pre-plant/pre-emergence herbicides depend on rainfall to trigger the active ingredients soon after application. Once in the soil, they must be mobile and persistent for a sufficient period of time to make contact with and destroy weed seedlings throughout the expected weed germination period. These enhanced mobility and persistence properties also facilitate the migration of such chemicals in the environment through surface-water runoff or percolation to ground water.

Burndown herbicides, more important in no-till systems, are nonselective and are used before or just after planting but prior to crop emergence. Post-emergence herbicides are successful in controlling problem weeds or escapes well into the growing season without damaging the crop or reducing yield potential and are generally unaffected by soil type or amount of crop residue on the surface. However, post-emergent application does depend on proper timing and correct identification of the target weeds. Post-emergence and burndown herbicides frequently have short or no residual soil effects (CTIC, 1996). They are generally less mobile and less persistent than pre-emergence herbicides and, therefore, less likely to migrate from their target. Pesticides applied to plant foliage, for instance, leave pesticide deposits that are highly vulnerable to photolysis and other degradation processes that reduce persistence and the potential for water pollution (Wauchope and others, 1992). For example, glyphosate and paraquat, although highly soluble, are

strongly adsorbed to the targeted material or the soil and rapidly converted to relatively harmless degradation products that reduce their potential for contaminating ground water (Melvin, 1995; Moldenhauer and others, 1995).

The difference in chemical properties between the different classes of herbicides is important when considering the environmental impacts of herbicide use between tillage systems. Tillage systems that employ herbicides with lower mobility and shorter persistence are preferable from a water-quality standpoint to tillage systems that require herbicides with greater mobility and longer persistence (Melvin, 1995; Wauchope and others, 1992).

The inherent toxicity of the active ingredients and their degradation, the impact of these products on nontarget species, and their mobility and persistence in soil and water determine their relative impact on the environment. In addition, a specific active ingredient can be converted by environmental processes including hydrolysis, photolysis, and other processes into an important degradation product with different chemical properties (Wauchope and others, 1992). Tillage systems employing newer pesticides that are highly toxic to targeted species but are used at much lower rates may be more environmentally desirable. For a given chemical, the amount of active ingredient being dissipated into the environment is generally proportionate to the amount applied; as a result, lower application rates translate into reduced exposure of nontarget species to the side effects of these chemicals (Wauchope and others, 1992).

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References

- Baker, J. L. (1980). "Agricultural Areas as Nonpoint Sources of Pollution." In M. R. Overcash and J. M. Davidson [eds.] *Environmental Impact of Nonpoint Source Pollution*. Ann Arbor Science Publications, Inc., Ann Arbor, MI, pp. 275-310.
- Baker, J. L. (1987). "Hydrologic Effects of Conservation Tillage and Their Importance to Water Quality." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 113-124.
- Baker, J. L. and H. P. Johnson (1979). "The Effect of Tillage System on Pesticides in Runoff from Small Water-

- sheds." Trans. American Society of Agricultural Engineers, 22: 554-559.
- Baker, J. L. and J. M. Laflen (1979). "Runoff Losses of Surface-applied Herbicides as Affected by Wheel Tracks and Incorporation." *Journal of Environmental Quality*, 8: 602-607.
- Baker, J. L., T. J. Logan, J. M. Davidson, and M. R. Overcash (1987). "Summary and Conclusions." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 277-281.
- Bengtson, R. L., L. M. Southwick, G. H. Willis, and C. E. Carter (1989). "The Influence of Subsurface Drainage Practices on Herbicide Loss." Paper 89-2130. American Society of Agricultural Engineers, St. Joseph, MI.
- Bull, Len. (1993). "Residue and Tillage Systems for Field Crops" Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Staff Report No. AGES 9310, July.
- Bull, Len, and Carmen Sandretto (1996). *Crop Residue Management and Tillage System Trends*, Natural Resources and Environment Division, Economic Research Service, U.S. Department of Agriculture. Statistical Bulletin No. 930.
- Bull, Len, and Carmen Sandretto (1995). "The Economics of Agricultural Tillage Systems." *Farming for a Better Environment: A White Paper*. Soil and Water Conservation Society, Ankeny, IA, pp. 35-37.
- Bull, Len, Herman Delvo, Carmen Sandretto, and Bill Lindamood (1993). "Analysis of Pesticide Use by Tillage System in 1990, 1991 and 1992 Corn and Soybeans." *Agricultural Resources: Inputs Situation and Outlook Report*, AR-32, ERS, USDA, October.
- Clark, Richard T., James B. Johnson, and Jennifer Brundson (1994). "Economics of Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Northern Great Plains Region*. (W.C. Moldenhauer and A.L. Black, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 38.
- Conservation Technology Information Center (1996). *A Checklist for U.S. Farmers*, West Lafayette, IN.
- Dick, W. A. and T. C. Daniel (1987). "Soil Chemical and Biological Properties as Affected by Conservation Tillage: Environmental Implications." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 125-147.
- Doster, D.H., T. W. Pritchard, D. R. Griffith, and S. D. Parsons (1994). "Tillage Economics, One Planter Farms." ID-191. Purdue University Cooperative Extension Service.
- Edwards, William M. (1995). "Effects of Tillage and Residue Management on Water for Crops," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Appalachia and Northeast Region* (R.L. Blevins and W.C. Moldenhauer, eds.). USDA Agricultural Research Service, Conservation Research Report No. 41.
- Edwards, William M., M. J. Shipitalo, L. B. Owens, and W. A. Dick (1993). "Factors Affecting Preferential Flow of Water and Atrazine Through Earthworm Burrows under Continuous No-till Corn." *Journal of Environmental Quality*. Vol. 22, No. 3.
- Fawcett, Richard S. (1987). "Overview of Pest Management for Conservation Tillage Systems." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 19-37.
- Fawcett, Richard S., Dennis P. Tierney, Brian R. Christensen (1994). "Impact of Conservation Tillage on Reducing Runoff of Pesticides into Surface Waters." *Journal of Soil and Water Conservation*. Vol. 49, No. 2.
- Fox, G., A. Weersink, G. Sarwar, S. Duff, and B. Deen (1991). "Comparative Economics of Alternative Agricultural Production Systems: A Review." *Northeastern Journal of Agricultural and Resource Economics*. Vol. 30, No. 1.
- Gadsby, Dwight M., Richard S. Magleby, and Carmen L. Sandretto (1987). "Why Practice Conservation." *Soil and Water Conservation News*. Vol. 8, No. 9.
- Glenn, S. and J. S. Angle (1987). "Atrazine and Simazine in Runoff from Conventional and No-Till Corn Watersheds." *Agricultural Ecosystems and Environment*, 18: 273-280.
- Griffith, D. R., E. J. Kladvko, J. V. Mannering, T. D. West, and S. D. Parsons (1988). "Long Term Tillage and Rotation Effects on Corn Growth and Yield on High and Low Organic Matter, Poorly Drained Soils." *Agronomy Journal* No. 4, Pages 599-605.
- Griffith, D.R., J.F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Breitbach (1992). "Crop Response to Tillage Sys-

- tems." In *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till*. Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA, pp. 25-33.
- Hall, J. K., N. L. Hartwig, and L. D. Hoffman (1984). "Cyanazine Losses in Runoff from No-Tillage Corn in Living and Dead Mulches vs. Unmulched, Conventional Tillage," *Journal of Environmental Quality*, 13: 105-110.
- Hanthorn, M. and M. Duffy (1983). "Corn and Soybean Pest Management Practices for Alternative Tillage Strategies." Publication No. IOS-2, USDA/ERS, Washington, D. C.
- Helling, C. S. (1987). "Effect of Conservation Tillage on Pesticide Dissipation." T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, Michigan, pp. 179-187.
- Hudson, E. H. and J. F. Bradley (1995). "Economics of Surface-Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: Southeast Region* (G.W. Langdale and W.C. Moldenhauer, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 39.
- Kinsella, Jim. (1993). "Notes on Weed Control with Herbicides in the Production of Row Crops." Presented to Conservation Technology Information Center Executive Meeting, March 30.
- Martin, Alex R. (1995). "Weed Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region*. (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.
- Melvin, Stewart W. (1995). "Effects of Crop Residue Management on Water Quality," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region* (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.
- Mengel, D. B., J. F. Moncrief, and E. E. Schulte (1992). "Fertilizer Management," *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till*. Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA, pp. 83-87.
- Moldenhauer, W.C., W.D. Kemper, and L.N. Mielke (1995). "Long-Term Effects of Tillage and Crop Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region* (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.
- Monson, Mike and Nyle Wollenhaupt (1995). "Residue Management," *Crop Residue Management to Reduce Erosion and Improve Soil Quality: North Central Region* (W.C. Moldenhauer and L.N. Mielke, eds.) USDA, Agricultural Research Service, Conservation Research Report No. 42.
- Onstad, C. A. and W. B. Voorhees (1987). "Hydrologic Soil Parameters Affected by Tillage." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 95-112.
- Sander, K. W., W. W. Witt, and M. Barrett (1989). "Movement of Triazine Herbicides in Conventional and Conservation Tillage Systems." In D. L. Weigmann [ed.] *Pesticides in Terrestrial and Aquatic Environments*. Virginia Water Resources Center and Virginia Polytechnic Institute and State University, Blacksburg, pp. 378-382.
- Sandretto, Carmen and Len Bull (1996). "Conservation Tillage Gaining Ground," *Agricultural Outlook*, AO-232, Economic Research Service, U.S. Dept. Agr., August.
- Siemens, John C. and D. Howard Doster (1992). "Costs and Returns." In *Conservation Tillage Systems and Management, Crop Residue Management with No-till, Ridge-till, Mulch-till*. Midwest Plan Service, MWPS-45, First Edition, Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA, pp. 34-41.
- U.S. Dept. of Agriculture, Economic Research Service (1993). "Water Quality Effects of Crop Residue Management." *Agricultural Resources: Cropland, Water, and Conservation Situation and Outlook Report*, AR-30, May.
- Wagenet, R. J. (1987). "Processes Influencing Pesticide Loss with Water under Conservation Tillage," T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 189-204.
- Wauchope, R. D. (1987). "Effects of Conservation Tillage on Pesticide Loss with Water." In T. J. Logan, J. M. David-

Recent ERS Reports on Crop Residue Management

"Conservation Tillage Gaining Ground," AO-232, August 1996 (Carmen Sandretto and Len Bull). This special article discusses recent trends in conservation tillage practice adoption and describes some of the benefits and limitations associated with their use on major field crops. Conservation tillage practices such as no-till, ridge-till, and mulch-till were expected to be used on a record-high 103 million acres in 1996 (more than one-third of U.S. planted cropland), with most of the growth due to rapid expansion in the adoption of no-till which nearly tripled between 1989 and 1995 to almost 41 million acres. Expanded use of no-till has been greater for row crops such as corn and soybeans than for small grains or sorghum.

Crop Residue Management and Tillage System Trends, SB-930, August 1996 (Len Bull and Carmen Sandretto). Trends in national and regional use of crop residue management show that conservation tillage use expanded from 72 million acres in 1989 to more than 99 million acres in 1994. Tillage systems use on major field crops is presented for 1988-94 and by surveyed States for 1994.

Soil Erosion and Conservation in the United States: An Overview, AIB-718, September 1995 (Richard Magleby, Carmen Sandretto, William Crosswhite, and C. Tim Osborn). This report provides background information on soil use, erosion, and conservation policies and programs; summarizes assessments of economic and environmental effects of erosion; and discusses policies and programs as well as options for their improvement.

"Analysis of Pesticide Use by Tillage System in 1990, 1991, and 1992 Corn and Soybeans," AR-32, October 1993 (Len Bull, Herman Delvo, Carmen Sandretto, and Bill Lindamood). This special article examines the relationship between pesticide use and tillage systems in the production of corn and soybeans in 1990, 1991, and 1992. Little difference between tillage systems was observed in the percentage of acres treated or in the number of herbicide treatments. Average pounds of herbicide active ingredients applied did not exhibit a consistent pattern across tillage systems over the three year period. Among tillage systems, about 40-50 percent of the herbicide acre-treatments were combination mixes of more than one active ingredient, but no-till was the exception with about 50-60 percent being combination mixes. Corn insecticide applications were not significantly different between tillage systems, although no-till acreage received lower application amounts for each year.

"Water Quality Effects of Crop Residue Management," AR-30, May 1993 (Carmen Sandretto). This special supplement points out that crop residue management in combination with other appropriate management strategies and the proper selection and use of chemicals can play a crucial role in protecting water quality. The movement of agricultural chemicals from the point of application to ground or surface waters depends on a complex set of interactions between a variety of site specific factors ranging from the climate and the hydrologic, geologic, and topographic characteristics of the land surface, and the chemical carriers—sediment, surface runoff, and subsurface drainage water—and the respective properties of the active ingredients of the applied chemicals, such as their adsorption, persistence, solubility, and volatility characteristics.

son, J. L. Baker, and M. R. Overcash [eds.] *Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides*. Lewis Pub., Chelsea, MI, pp. 205-215.

Wauchope, R. D., T. M. Buttler, A. G. Hornsby, P. W. M. Augustijn Beckers, and J. P. Burt (1992). The SCS/ARS/CES Pesticide Properties Database for Environmental Decision-making. Published as Volume 123 (164 pages) of *Reviews of Environmental Contamination and Toxicology* by Springer-Verlag, NY.

Weber, J. B. and R. L. Warren (1993). "Herbicide Behavior in Soils: A Pesticide/Soil Ranking System for Minimizing Ground Water Contamination." *Proceedings of the Northeastern Weed Science Society*, 47.

Weersink, A., M. Walker, C. Swanton and F.E. Shaw (1992). "Costs of Conventional and Conservation Tillage Systems." *Journal of Soil and Water Conservation*. Vol. 47, No. 4.

Young, Douglas L., Tae-Jin Kwon, and Frank L. Young (1994). "Profit and Risk for Integrated Conservation Farming Systems in the Palouse." *Journal of Soil and Water Conservation*. Vol. 49, No. 6.